CFD-Driven Optimization of Room Airflow Patterns And Their Effect on Hood Containment for Flexible Laboratories of the Future

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Modern Laboratory Containment Demands

Balance enclosure

Powder handling

Robotic/High throughput technologies

Containment Performance Characteristics

Work area airflow distribution

- Ensure non-turbulent, unidirectional airflow distribution
- Provide ergonomic design and ensure ease of access
- Address energy efficiency concerns

Operator presence, laboratory operation

- Instantaneous disturbances at the face of the hood
- Dynamic airflow distribution in the Laboratory

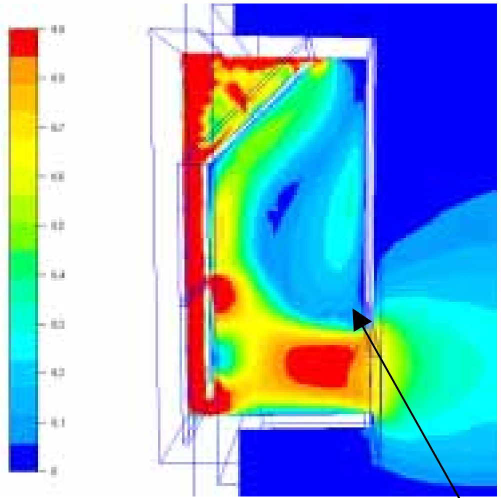
Laboratory airflow patterns

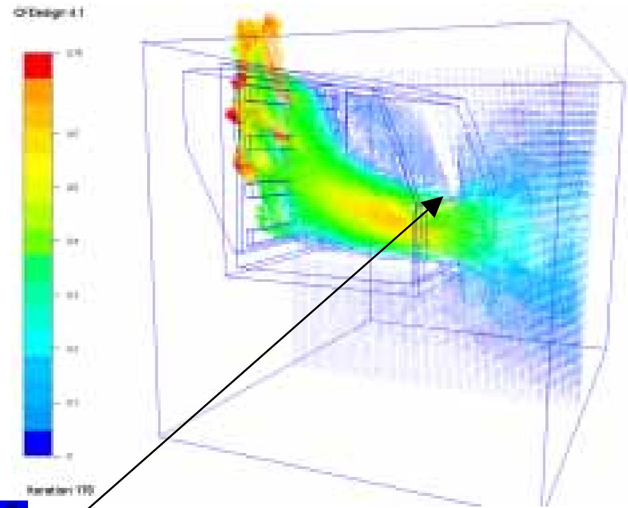
- Hood position
- Diffuser blanking
- Diffuser/hood position
- Diffuser/hood separation
- Transfer grilles
- Make up air distribution

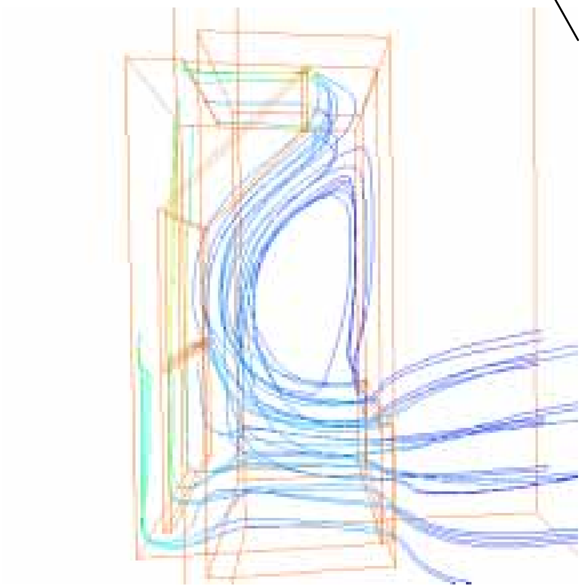
CFD Airflow modeling

Typical fume hood

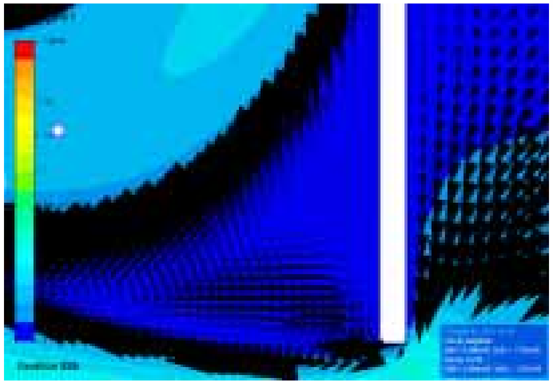
Typical Flow Sciences enclosure

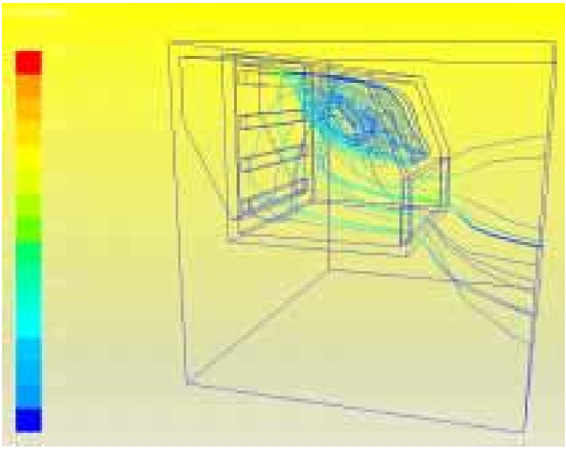






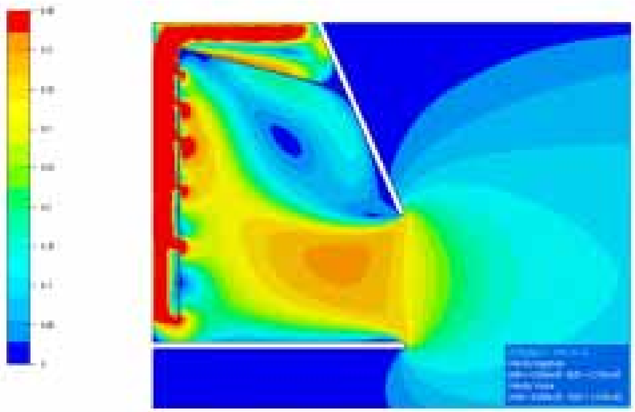
Sash door airflow detail



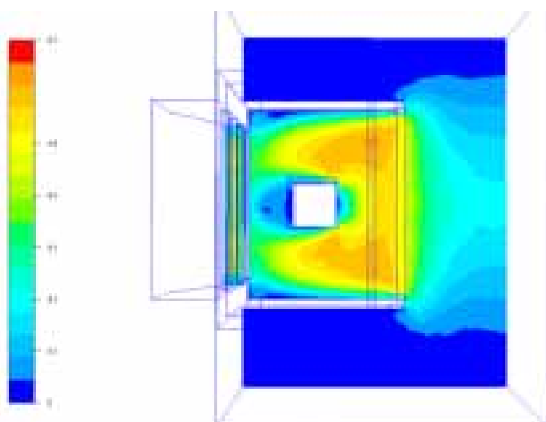


CFD Airflow modeling details

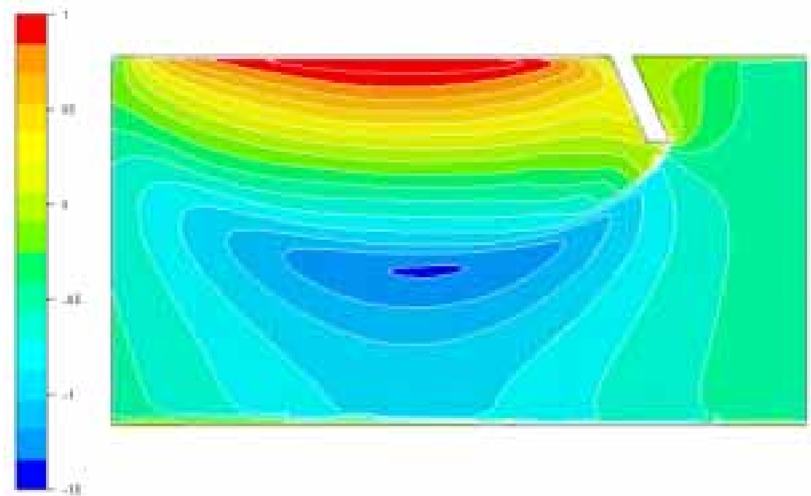
Exhaust slots configuration

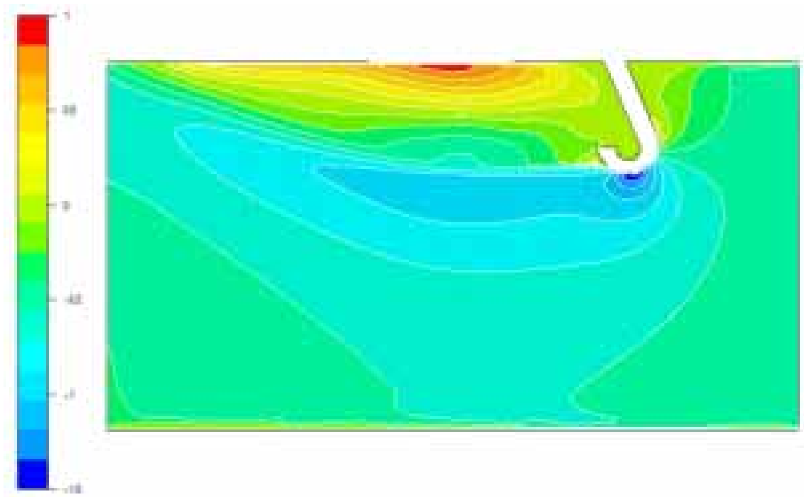


Equipment arrangement



Airfoil design optimization

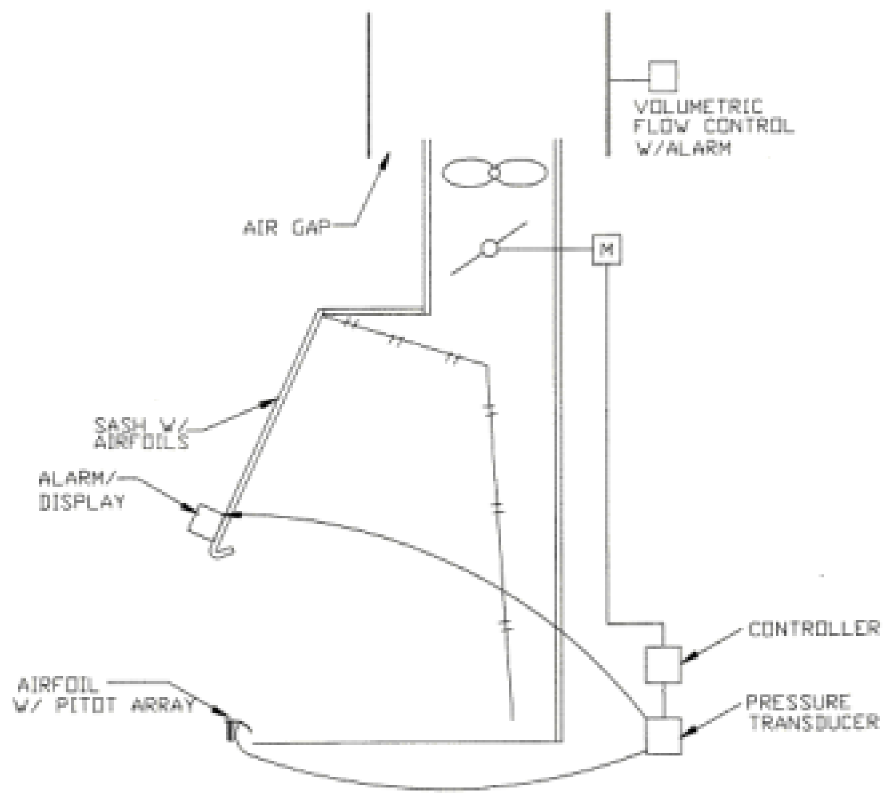




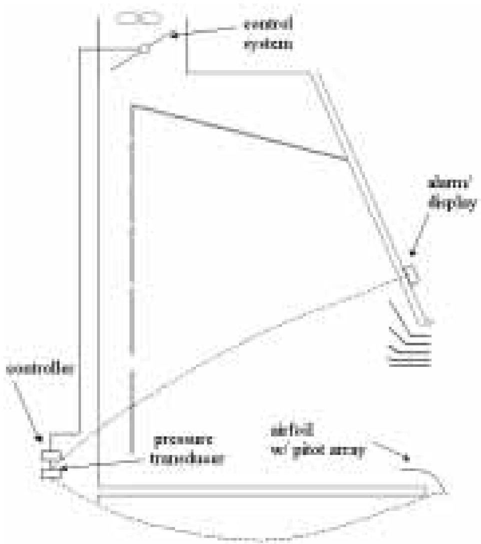
Variable Air Volume Control System

Rapid recovery containment control system

- Virtually instantaneous response
- Direct flow control measurement (pressure)
- Primary design focus on containment / safety
- Additional benefit of reduced energy consumption
- Direct coupling between hood design optimization and containment control system performance

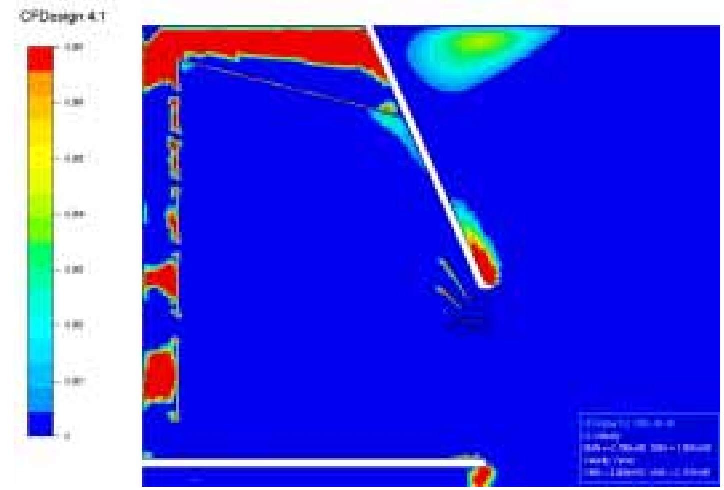


Prototype development



Final design
- ***flexible***
- ***portable***
- ***efficient***

Patent pending



- Recirculation-free laminar airflow for maximum safety
- Variable Air Volume control system for sash door cross-current compensation
- Low airflow energy efficient design
- Ergonomic “telescoping” sash configuration

Room airflow modeling and hood containment optimization

Containment performance parameters

- Room geometry
- Mechanical HVAC equipment
- Diffuser type and placement
- Operational procedures

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Room airflow modeling and hood containment optimization

Current Laboratory guidelines are designed to promote containment inside the hood

↓

They DO NOT address the fact the containment performance is linked with the air movement in the laboratory around the sash opening

↓

The problem is compounded by the modern Laboratory flexibility demands

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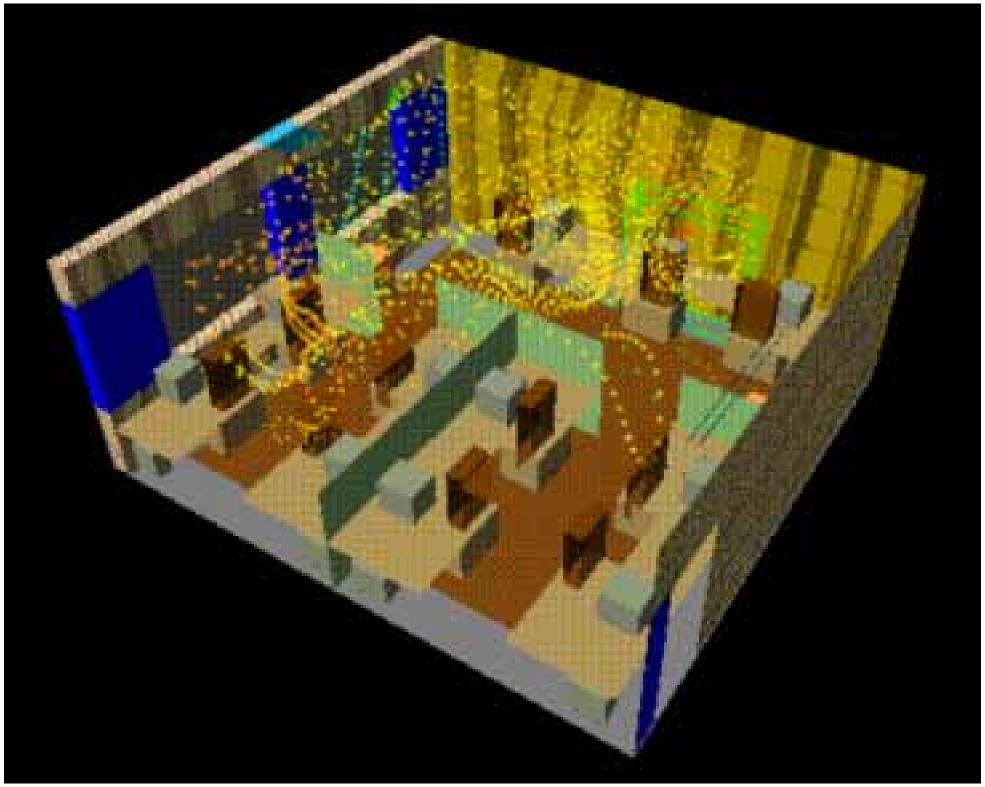
Experimental tests are costly, provide limited data and identify the problem only after the laboratory has been designed and built

Room airflow modeling and hood containment optimization

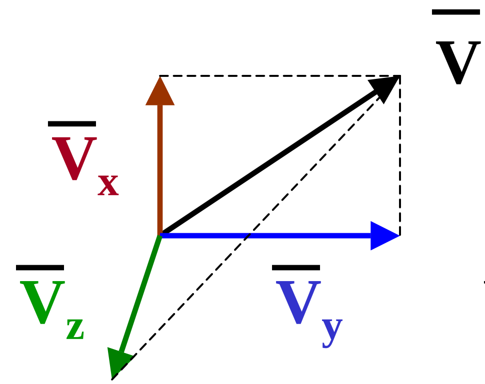
Possible recommendations



- Hood position
- Diffuser blanking
- Diffuser/hood position
- Diffuser/hood separation
- Transfer grilles
- Make up air distribution
- Hood separation, same wall
- Hood separation, opposite walls
- Hood separation, perpendicular walls

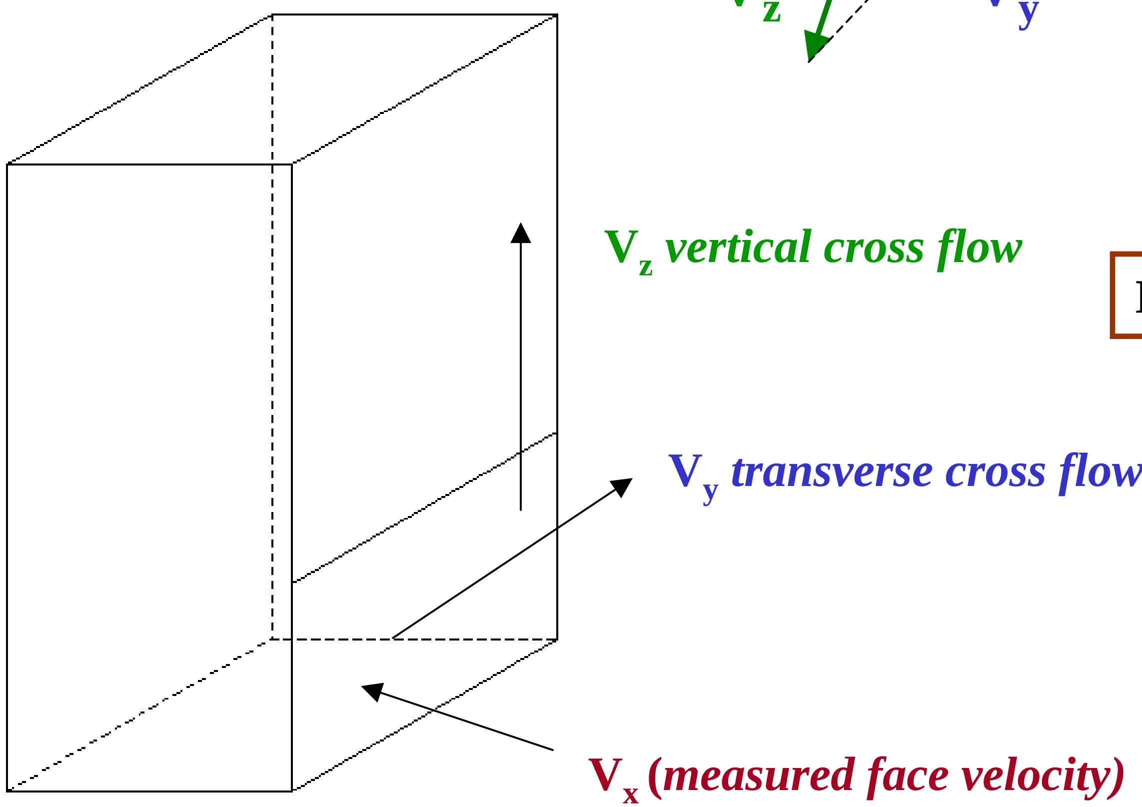
Room airflow. Face velocity distribution

Velocity vector



$$\overline{V} = \overline{V}_x + \overline{V}_y + \overline{V}_z$$

$$V^2 = V_x^{\,2} + V_y^{\,2} + V_z^{\,2}$$



Ideal airflow distribution

$$V = V_x$$

$$V_y = 0$$

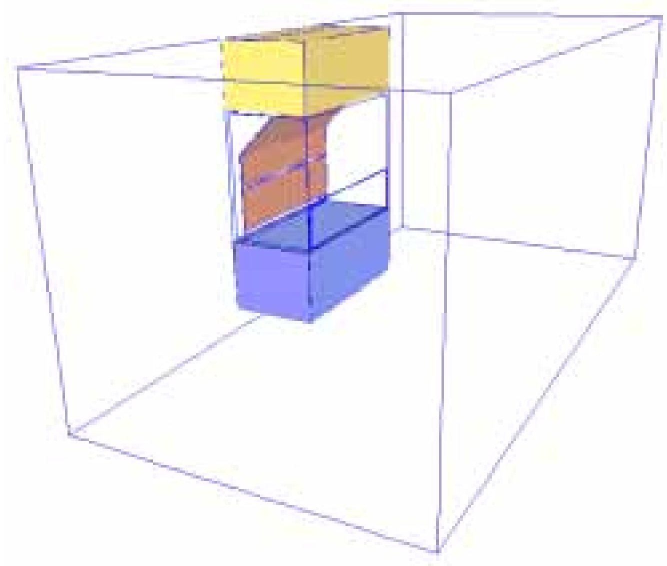
$$V_z = 0$$

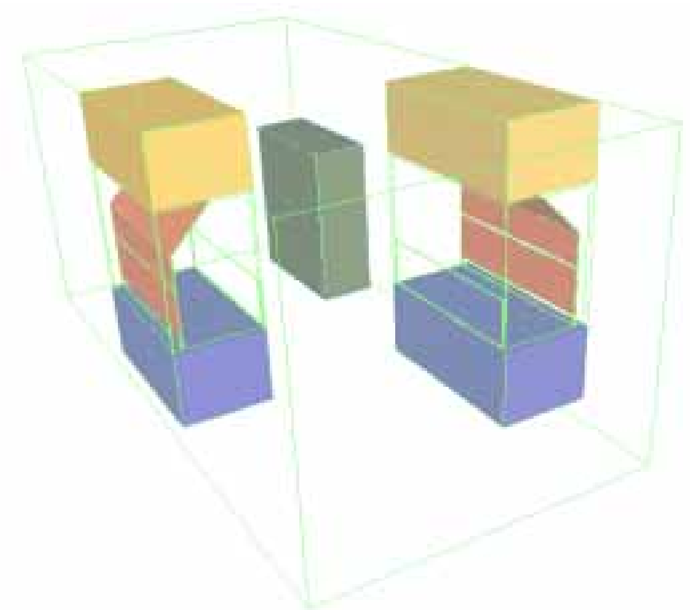
Model Configurations

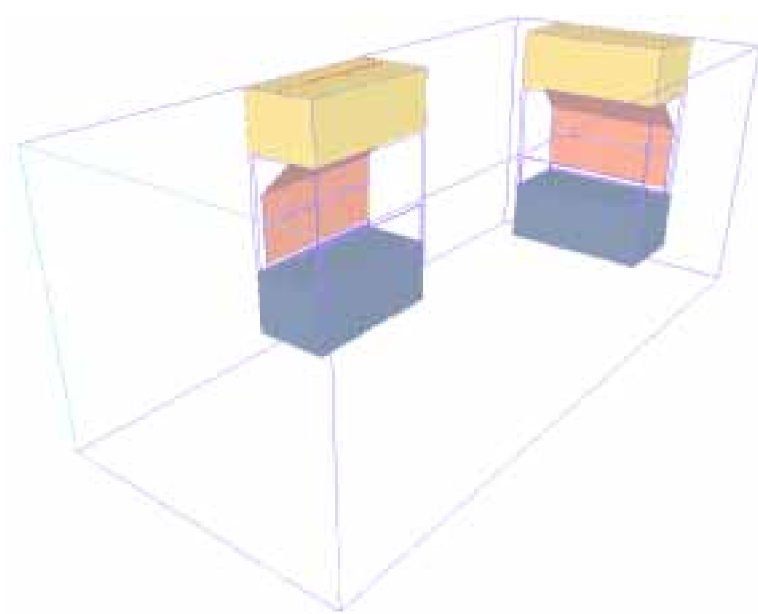
•Hood in isolation (ideal testing conditions)

•Two hoods, opposite walls

•Two hoods, adjacent walls

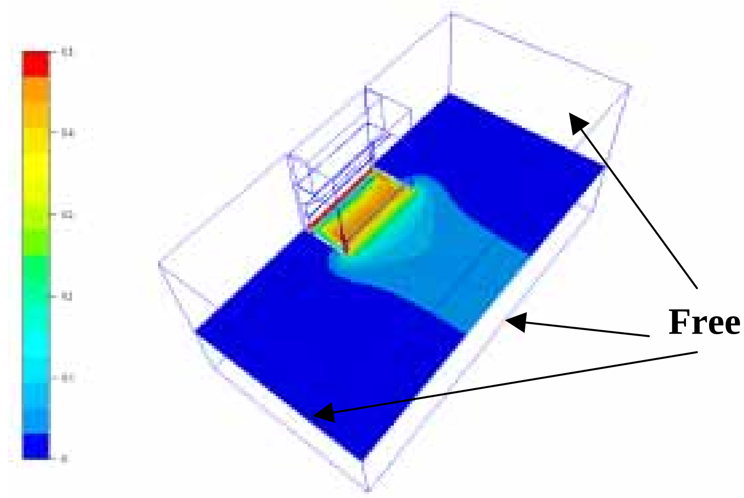






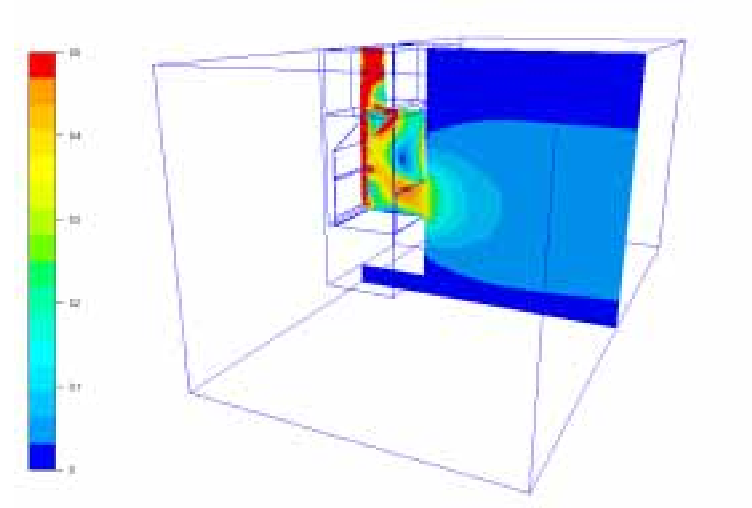
Single Hood in Isolation

Velocity magnitude. Top view



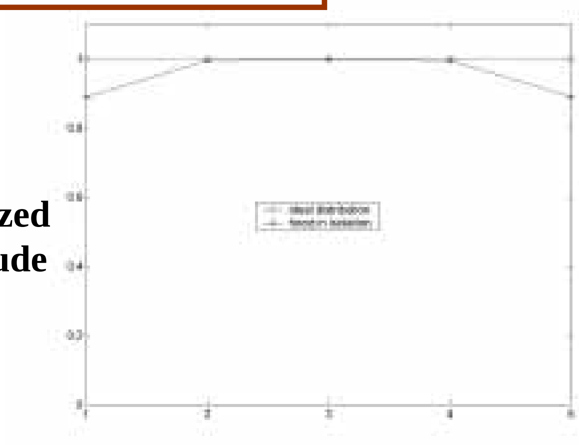
Free wall

Velocity magnitude. Cross view



Inflow distribution

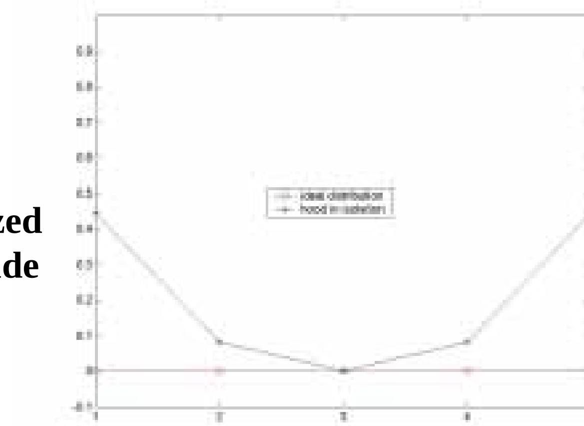
Normalized Magnitude



Node number

Cross flow distribution

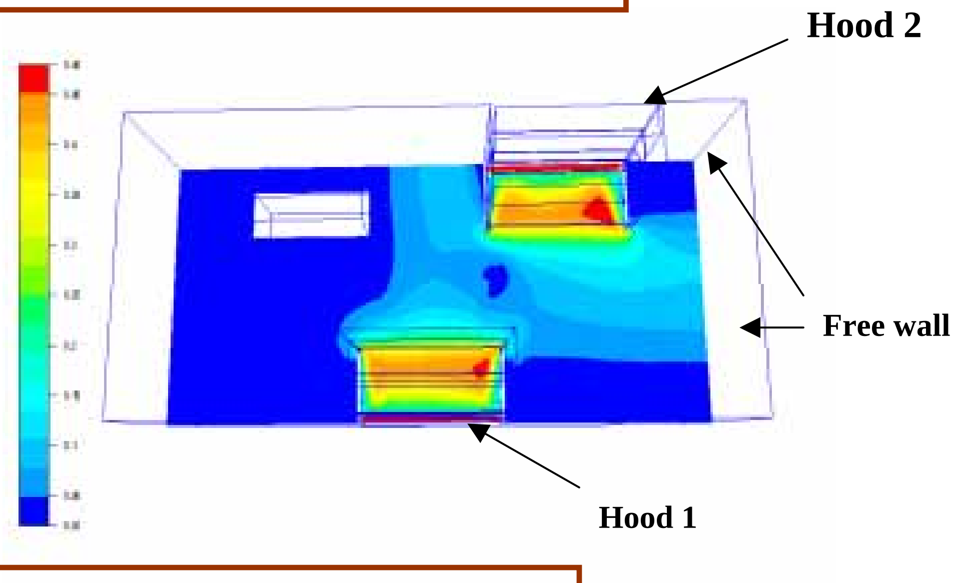
Normalized Magnitude



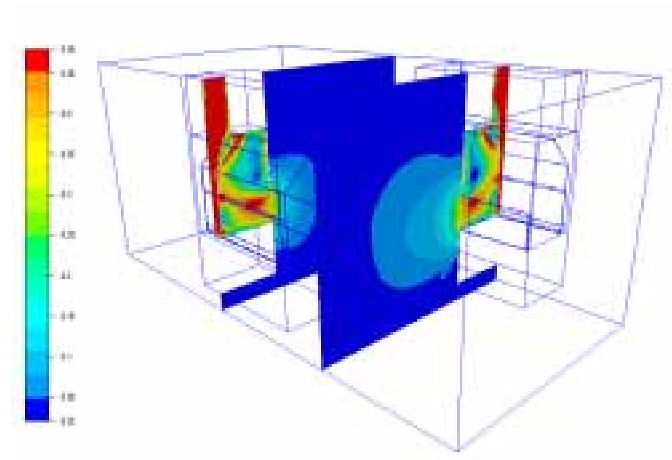
Node number

Hood separation. Opposite walls

Velocity magnitude. Top view

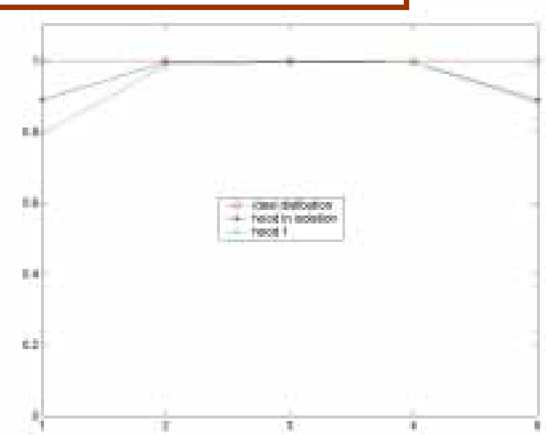


Velocity magnitude. Cross view



Inflow distribution, Hood 1

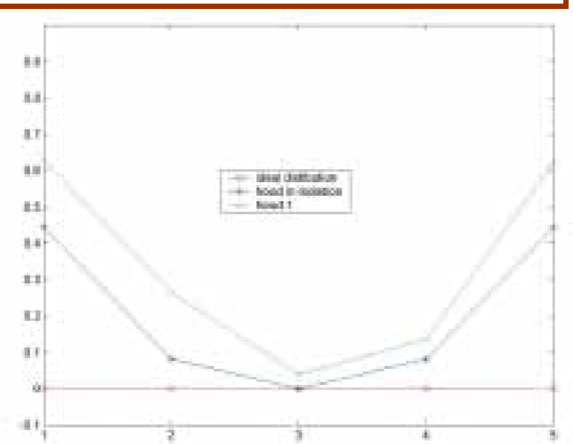
Normalized Magnitude



Node number

Cross flow distribution, Hood 1

Normalized Magnitude



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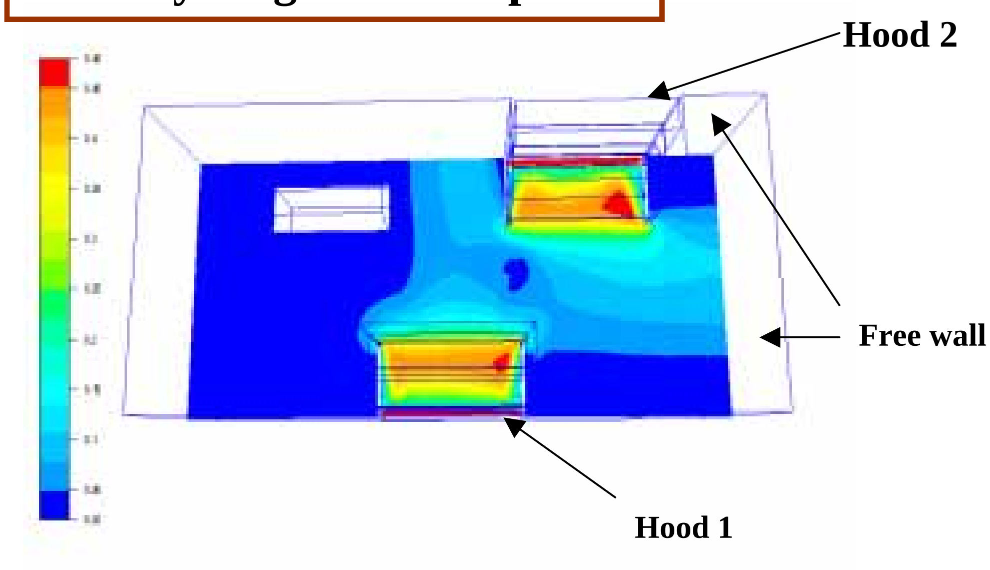
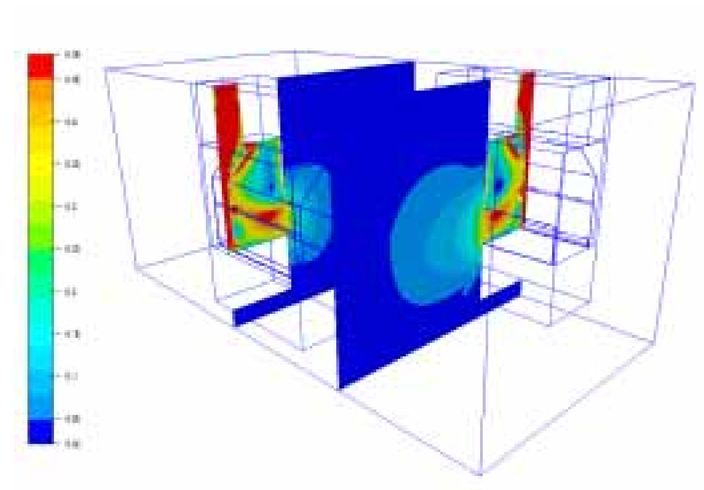
Hood separation. Opposite walls

Velocity magnitude. Top view

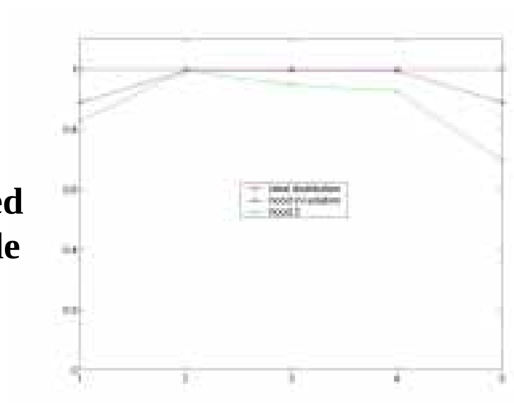


Velocity magnitude. Cross view



Inflow distribution, Hood 2

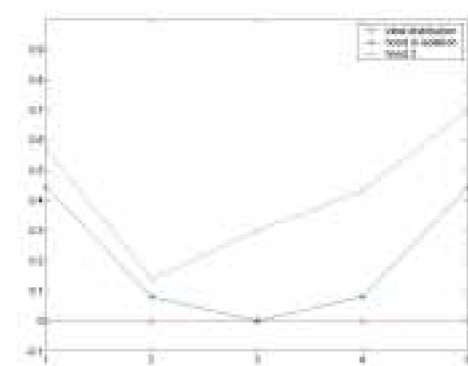
Normalized Magnitude



Node number

Cross flow distribution, Hood 2

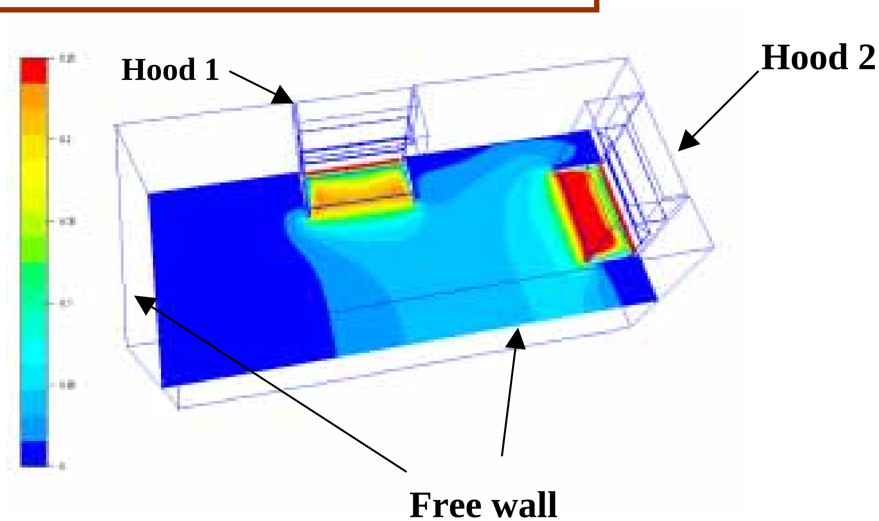
Normalized Magnitude



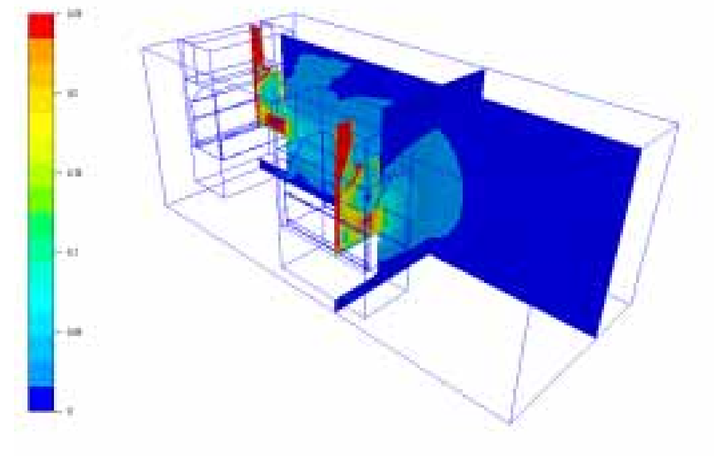
Node number

Hood separation. Perpendicular walls

Velocity magnitude. Top view

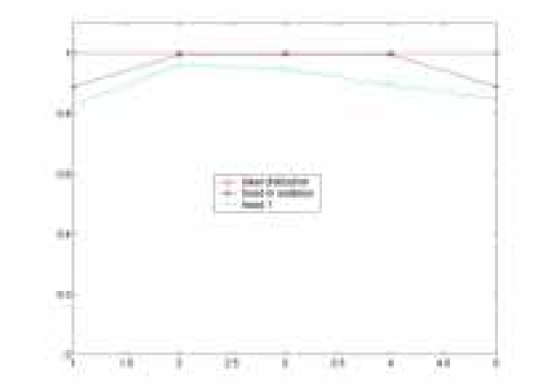


Velocity magnitude. Cross view



Inflow distribution, Hood 1

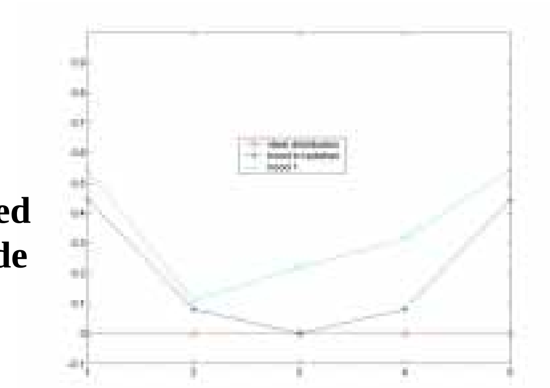
Normalized Magnitude



Node number

Cross flow distribution, Hood 1

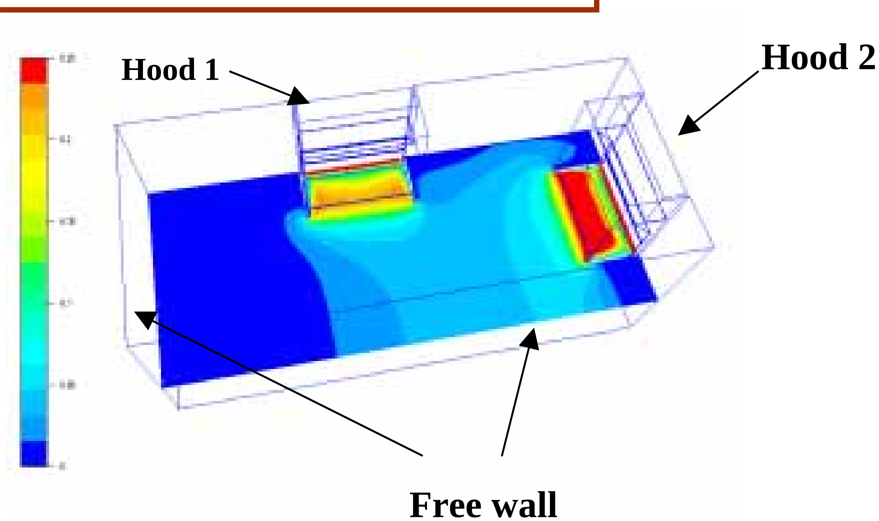
Normalized Magnitude



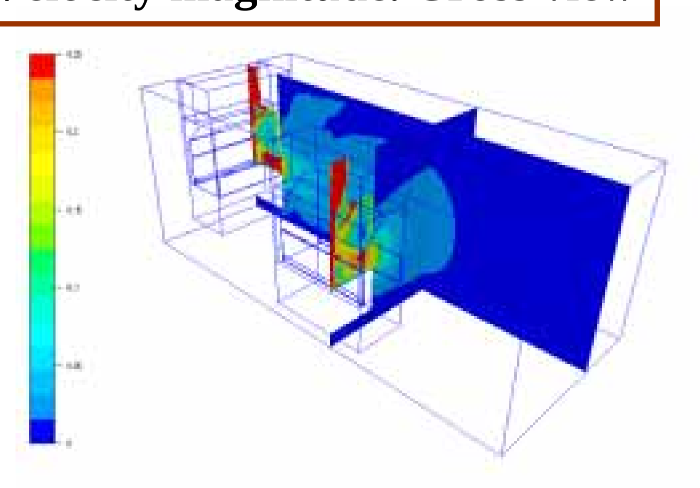
Node number

Hood separation. Perpendicular walls

Velocity magnitude. Top view

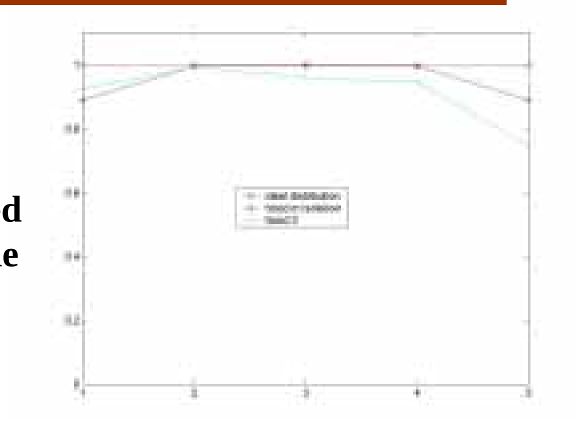


Velocity magnitude. Cross view



Inflow distribution, Hood 2

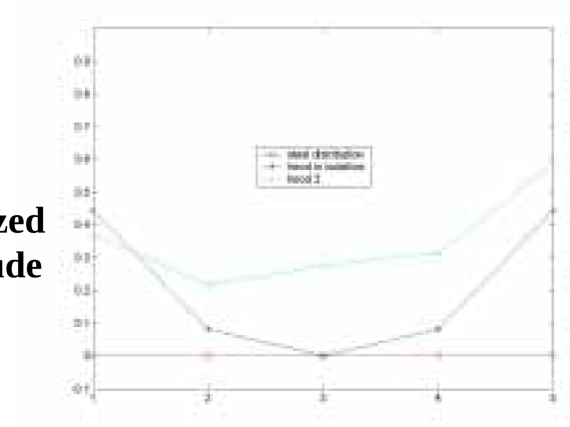
Normalized Magnitude



Node number

Cross flow distribution, Hood 2

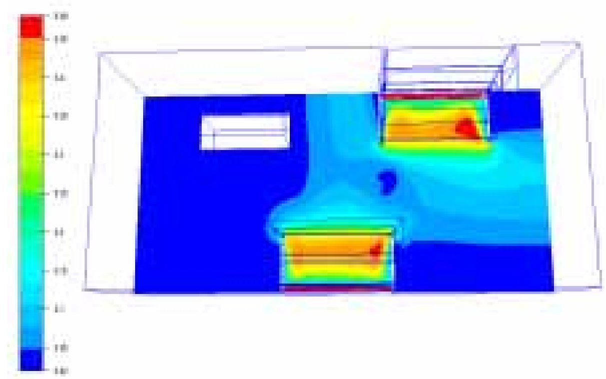
Normalized Magnitude



Node number

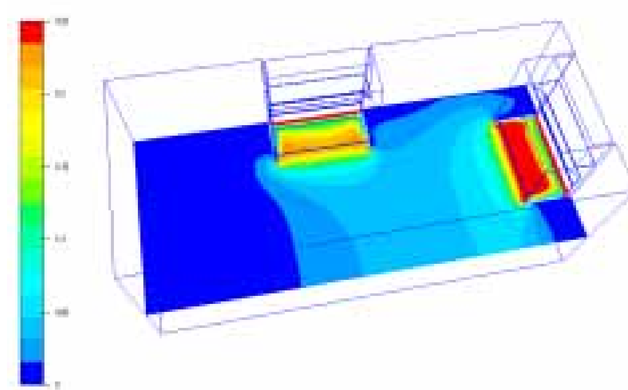
Potential recommendations. Additional considerations

Hood positioning recommendations



- Avoid positioning hoods next to a perpendicular wall
- Avoid placing hoods close to each other at perpendicular walls
- Provide sufficient space at the hood face opening to ensure positive incoming flow distribution
- Avoid positioning hoods next to doors, windows and high traffic areas

Additional considerations



- Diffuser blanking
- Diffuser/hood position
- Diffuser/hood separation
- Transfer grilles
- Make up air distribution

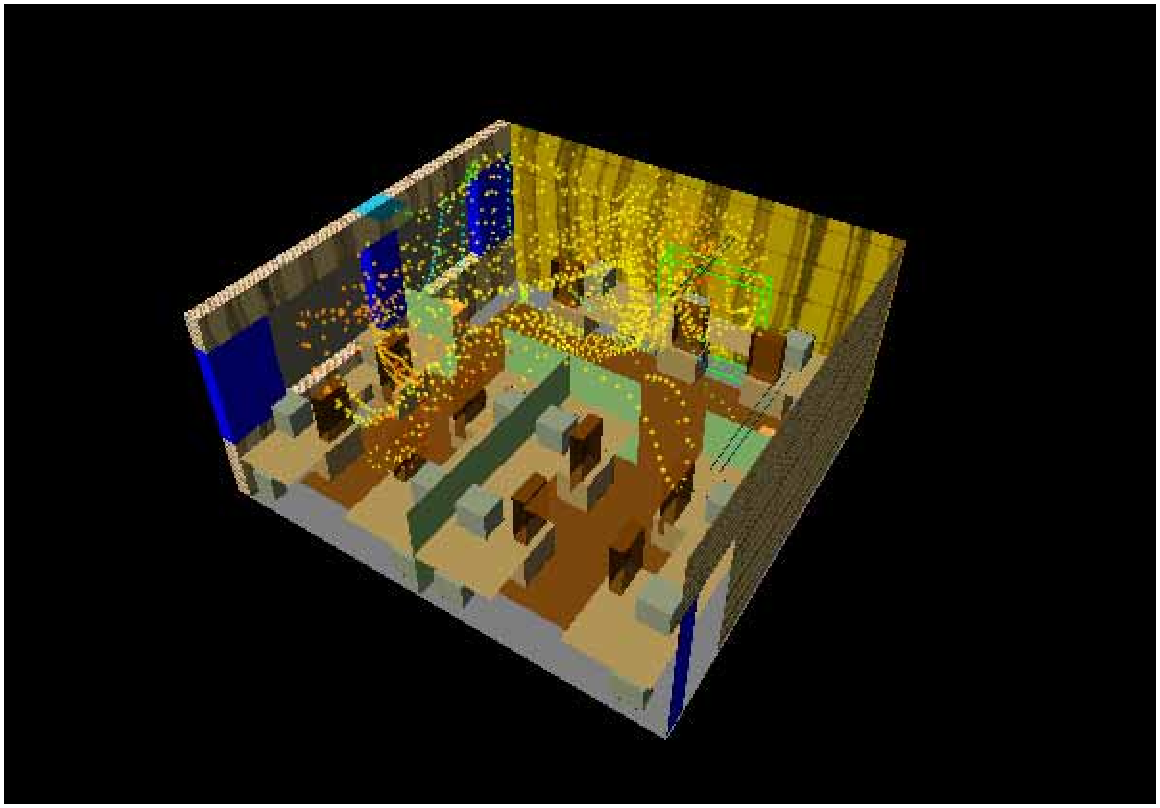
CFD room airflow modeling

CFD simulation protocols are very detailed

- Mathematics
- Physics
- Computer science

CFD provides data otherwise absolutely unavailable

- Repeatability
- Parametric variation
  (hood, furniture, supply, exhaust)
- Density of data



Room airflow modeling and hood containment optimization

•Safety

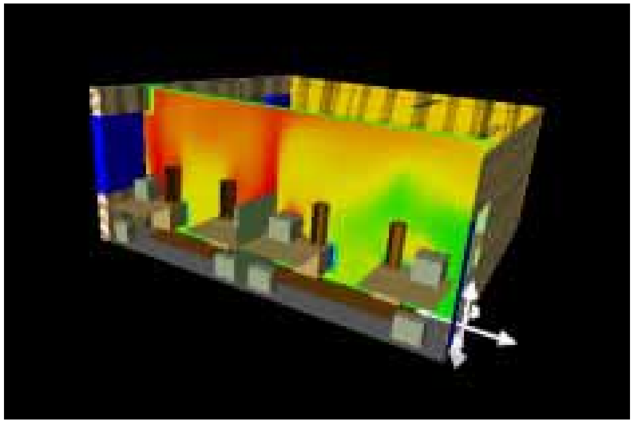
Predict and optimize the containment performance of the complete laboratory/hood airflow system

•Flexibility

Be able to make changes to the entire system layout knowing the exact effect of such variations

•Energy conservation

Use only enough air changes per hour to satisfy the requirements. Hood face velocity optimization



Project Cost Benefits

•Design optimization prior to construction or mock-up

•Project time reduction via established CFD data management protocols utilization

•Energy demand minimization